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DIRECT RESTORING OF MAGNETIC FIELD LINES IN THE MAGNETOSPHERE FROM OBSERVATION DATA

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Abstract. The database of *Fairfield et al*. [1994] has been used for drawing magnetic field lines in the magnetosphere at distances of $r < 40\ R_E$. The field of the magnetospheric currents was averaged in the cubic bins with the linear size of 2 R_E. The total field is the sum of fields of the magnetospheric currents and of the Earth dipole. The magnetic field lines are built under various values of the *Dst* and *Kp* indices, solar wind dynamic pressure P_{sw}, and vertical component of the interplanetary magnetic field B_zIMF. The configuration of the magnetic field lines appeared to be most sensitive to the *Dst* and *Kp*. The latitude of the dayside polar cusp decreases by 1 degree when either *Dst* falls by 14 nT or *Kp* grows by 0.7. Such a decrease exceeds that in the model by *Tsyganenko* [1995] several times and agrees well with observations. Storms stretch the magnetotail, whereas substorms somewhat dipolarize it. The sizes of the magnetosphere as well as its day-night asymmetry depend mainly on the pressure P_{sw}. The influence of B_zIMF (providing *Dst*, *Kp*, and P_{sw} keep invariable) appeared to be negligible.

1. Introduction

Various magnetic field models are suggested by *Olson and Pfitzer* [1974], *Tsyganenko and Usmanov* [1982], *Tsyganenko* [1987, 1989, 1995; 1996], *Hilmer and Voigt* [1995], *Alexeev et al*. [1996], *Ostapenko and Maltsev* [1997]. The most models include certain hypotheses concerning the spatial distribution of the field in the magnetosphere thus their accuracy is dubious.

As a rule, the models are used for mapping some magnetospheric domains into the ionosphere and vice versa. However the domains may be mapped without a special magnetic field model. It is sufficient to use the experimental data directly. A large database described by *Fairfield at al*. [1994] contains 79,000 three-component magnetic measurements at distances from 3 to 60 R_E with spatial resolution of 0.5 R_E (in radial direction) and temporal resolution of 10-25 min. The database is obtained by 11 satellites measuring the field from 1966 to 1986. Hourly *Dst* and three-hourly *Kp* indices supply all magnetic measurements. 67 per cent of the measurements are accompanied by hourly magnitudes of the solar wind parameters.

In this paper we map the ionospheric coordinates into the magnetosphere directly from the database of *Fairfield at al*. [1994].

2. Technique of the magnetic field line tracing

The total magnetic field is the sum

$$\mathbf{B} = \mathbf{B}^{int} + \mathbf{B}^{ext}, \qquad (1)$$

where $\mathbf{B}^{int}$ is the field of internal electric currents flowing inside the Earth, $\mathbf{B}^{ext}$ is the field of external currents flowing in the magnetosphere.

We restrict ourselves with the region $10\ R_E > x > -40\ R_E$, $|y| < 20\ R_E$, $|z| < 20\ R_E$, $r > 3\ R_E$. The database of *Fairfield at al*. [1994] contains here 68,000 measurements of $\mathbf{B}^{ext}$. The space was divided into cubic bins with the size of 2 R_E. The data were averaged in the each spatial bin as well as in several ranges of the following geophysical parameters: *Dst* and *Kp* indices, the solar wind dynamic pressure P_{sw}, and the z component of the interplanetary magnetic field B_zIMF. The dawn-dusk and north-south symmetry was supposed.

The averaged field $\mathbf{B}^{ext}$ was considered to be uniform in the each bin. The total field was computed with the help of expression (1) where $\mathbf{B}^{int}$ was assumed to be dipolar. A magnetic field line was built beginning from the Earth surface along the direction of the total field. If the calculation reached a bin with a small number of data (less than 4) supplementary data from 6 neighboring bins were added. If the number of data remained less than 4 again, the calculation was stopped. The value 4 was chosen to avoid too sharp breaks of field lines owing to the data spread.

3. Field lines under average conditions

All 68,000 magnetic measurements were used. The average geophysical parameters are following: *Dst* = -16 nT, *Kp* = 2.2, P_{sw} = 2.2 nPa, B_zIMF = 0 nT. At distances $x > -10\ R_E$ we used the data from the solar-magnetic (SM) coordinate system with the *z* axis anti-parallel to the Earth dipole. In the magnetotail, at $x < -10\ R_E$, we used the solar-magnetospheric (GSM) coordinate system with the *x* axis directed sunward. We assumed $z = z_{GSM} - z_{ns}$ where z_{GSM} is the GSM coordinate, z_{ns} is the distance between the neutral sheet and the $z_{GSM} = 0$ plane [*Peredo et al,*. 1994.

Fig. 1a shows the magnetic field lines in the noon-midnight meridian plane (y = 0). The lines are drawn through 2°, beginning from 60° of latitude. Fig. 1b shows ionospheric latitudes (the solid lines) and longitudes (the dashed lines) mapped onto the equatorial plane (z = 0). The longitudes are drawn through 1 hour of local time. Figs. 1c and 1d show the same maps in the planes $x = -20\ R_E$ and $x = -10\ R_E$, respectively.

4. Effect of the dipole tilt

The data with $|\Psi| > 20°$ was chosen. Their amount was ~20,000. The average $|\Psi|$ in this subset is

27°, the other parameters being similar to those in the whole database. Fig. 2 shows the field lines in the noon-midnight meridian plane. The lines going from the

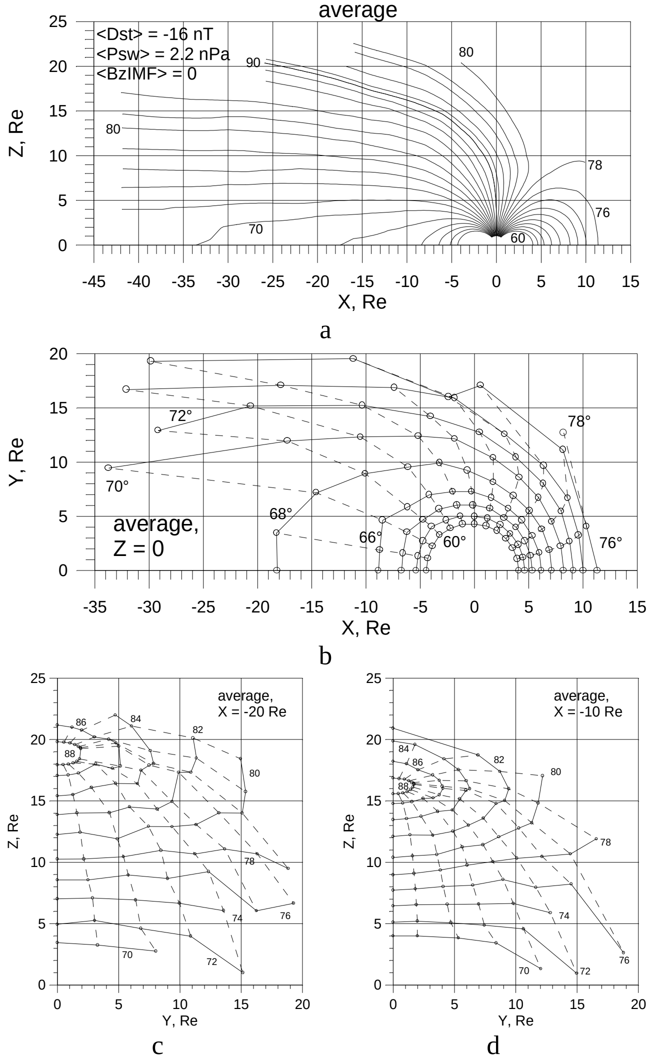

Fig. 1. Empirical configuration of magnetic field lines in the magnetosphere under average geophysical conditions: a) magnetic field lines in the noon-midnight meridian plane; b, c, and d) maps of latitudes (the solid lines) and longitudes (the dashed lines) onto the planes $y = 0$, $x = -20$ R_E, and $x = -10$ R_E, respectively.

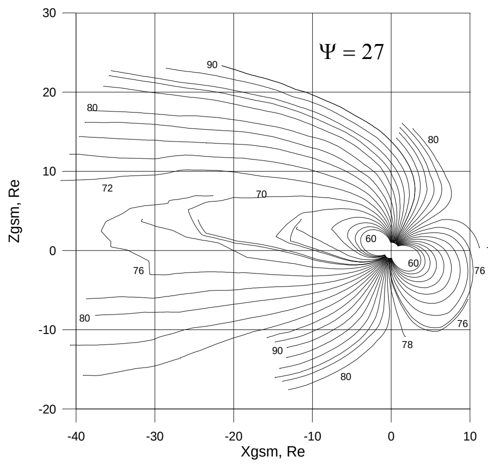

Fig. 2. Magnetic field lines in the noon-midnight meridian plane for the dipole tilt angle of 27° under average geomagnetic activity.

northern hemisphere are drawn through 2° beginning from 60° of latitude. The lines going from the southern hemisphere are drawn through 2°, beginning from 76° at noon up to 68° at midnight. In order not to overload the figure, the lines going from the southern hemisphere are torn near the equatorial plane.

One can see the hemispheres are not conjugate, especially at midnight. The line going from the winter hemisphere at the latitude of 76° comes to the summer one at ~71°.

5. Field lines under magnetic storm conditions

Data with *Dst* < -50 nT were chosen. This subset has the following average parameters: *Dst* = -74 nT, *Kp* = 4.3, P_{sw} = 3.4 nPa, B_zIMF = -2.2 nT, which correspond to a moderate storm. Computation results are shown in Fig. 3. Comparing Figs. 1 and 3 we can see that the storm time magnetosphere suffers strong changes: the dayside magnetosphere gets eroded, the dayside polar cusps shift equatorward (from ~78° under average conditions to ~69° under moderate storms), the field in the magnetotail grows.

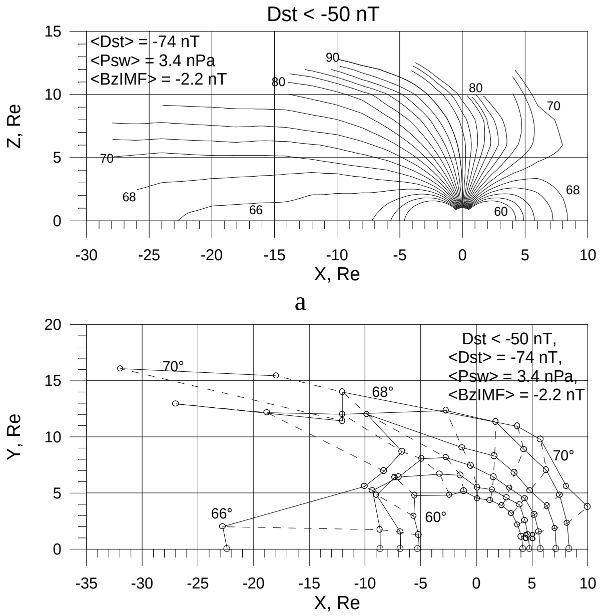

Fig. 3. The same as in Figs. 1ab, but under storm conditions.

6. Differential effects of various factors

We examined four cases when only one geophysical parameter (*Dst*, *Kp*, P_{sw}, or B_zIMF) changed, the other three parameters keeping invariable. With this purpose we divided the four-dimensional space (*Dst*, *Kp*, P_{sw}, B_zIMF) by a hyper plane into two half-spaces. Correspondingly, the whole data set containing 68,000 measurements was divided into two nearly equal subsets. The slope of the hyper plane was found so that three average geophysical parameters in the both subsets were equal. Only one parameter must differ. After drawing field lines for the each subset, we can see what is the effect of this parameter.

Fig. 4 shows the magnetic field lines in the noon-midnight meridian plane for the four pairs of subsets, each pair illustrating the effect of one parameter only. One can see that *Dst* subsiding from -4 nT to -31 nT decreases the cusp latitude by 2°. The same decrease occurs when *Kp* grows from 1.5 to 3. Influence of these indices on the field in the magnetotail is not equal.

When the storm enhances (*Dst* falls) the field lines stretch tailward. When the substorm activity enhances (*Kp* grows) the field lines become more dipole-like.

The growing solar wind dynamic pressure decreases the magnetospheric sizes and increases the day-night asymmetry at distances of 6-10 R_E. The IMF vertical component practically does not affect the shape of the field lines in the magnetosphere.

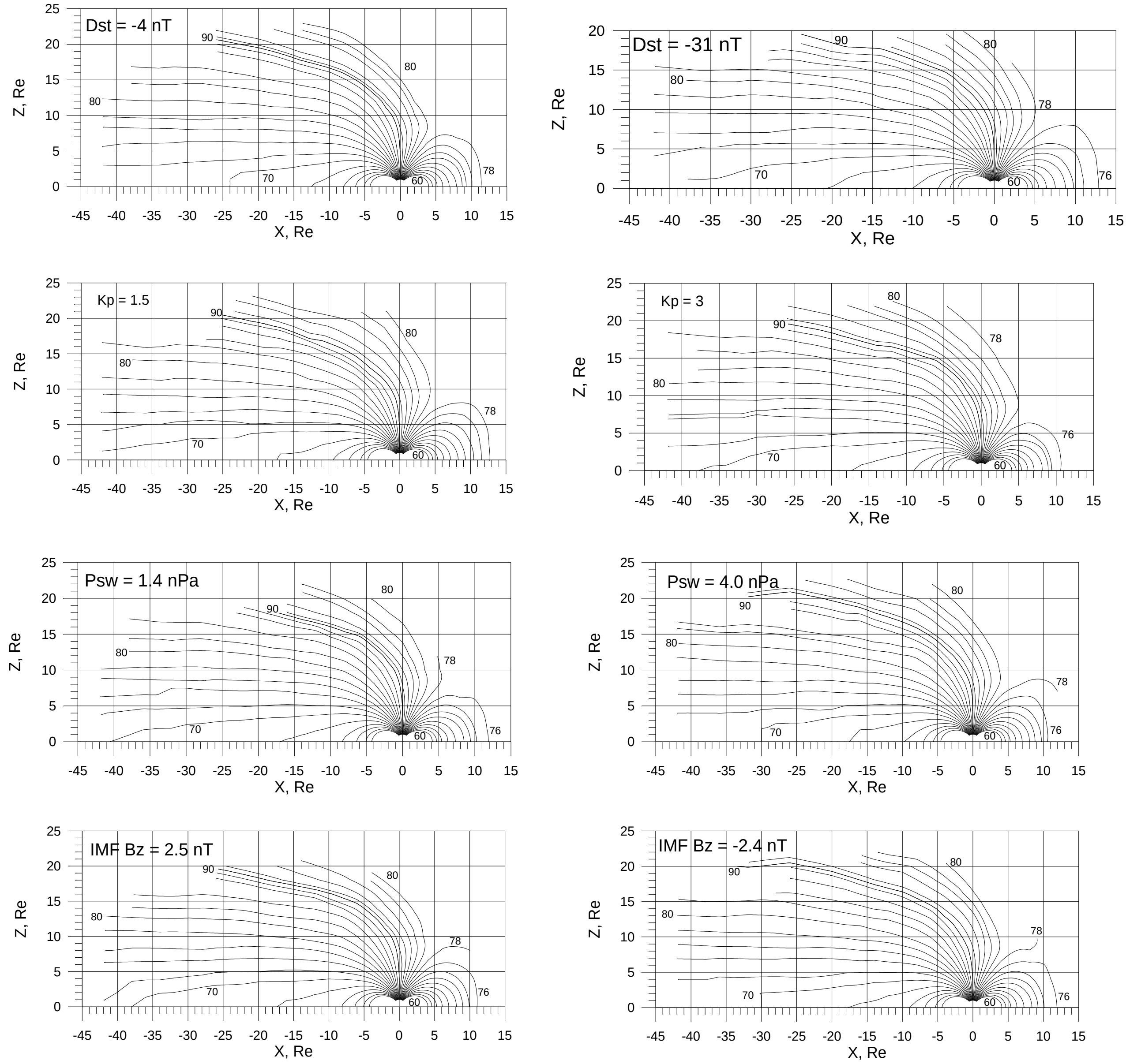

Fig. 4. Variation of magnetic field line pattern in the noon-midnight meridian plane under the influence of one geophysical parameter, providing the other parameters keep invariable. From top to bottom: the effects of *Dst* index, *Kp* index, solar wind dynamic pressure P_{sw}, IMF vertical component B_zIMF.

7. Discussion

Field lines in Figs. 1-4 appeared to be not very smooth. It is caused by the data spread. Nevertheless these lines seem to be more accurate than those in the previous models because they are built directly from experimental data whereas the previous models postulate a number of hypotheses concerning possible classes of solutions describing both the spatial behavior of the field and its dependence on various geophysical factors. But even if these hypotheses prove to be correct the direct restoring of magnetic field lines is of interest as it allows the obvious comparison of the modeling results with observations.

For comparing, in Fig. 5 we have shown the field lines according to the model by *Tsyganenko* [1995, 1996]. The model depends on 5 parameters: the *Dst* index, solar wind dynamic pressure, *y* and *z* IMF components, and dipole tilt. The field lines are calculated for the same conditions as in Figs. 1 and 3. One can see that the model by *Tsyganenko* [1995, 1996] for average conditions (Fig. 5a) does not differ practically from the purely empirical pattern (Fig. 1a). Large difference takes place under storm conditions (Figs. 5b and 3a). For instance, the empirical model yields the cusp position at 69°, whereas the model by *Tsyganenko* [1995, 1996] predicts 75° as the cusp latitude.

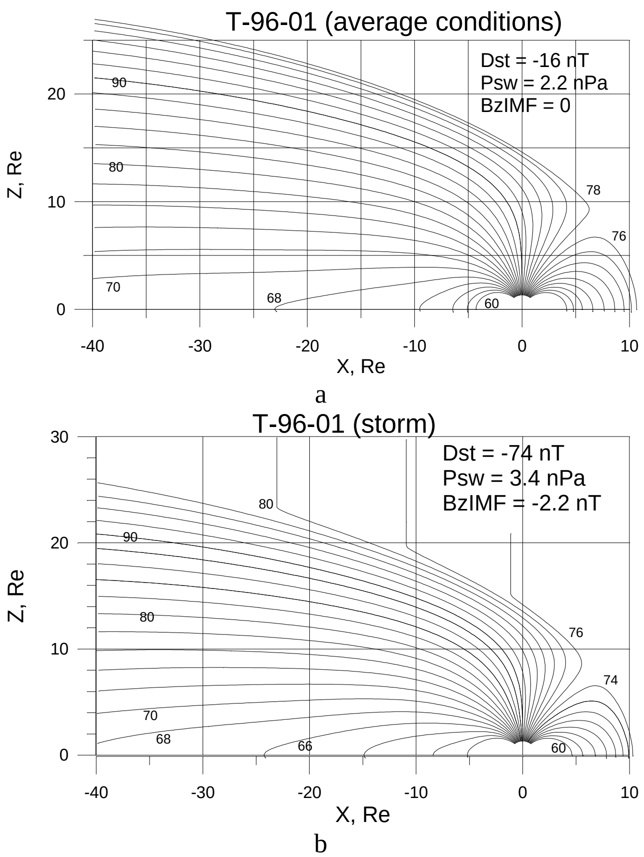

Fig. 5. Magnetic field lines in the noon-midnight meridian plane according to the model by *Tsyganenko* [1995, 1996] for average conditions (a) and for storms (b).

8. Conclusions

On the basis of the large number of measurements, the magnetic field line configuration has been built under various geophysical conditions.

The northern and southern hemispheres becomes strongly (up to 5°) non-conjugate due to the Earth dipole tilt.

Magnetic storms decrease the latitude of the dayside polar cusps, erode the dayside magnetopause, and stretch the nightside field lines tailward.

Variation in *Dst* and *Kp* indices has the most effect on the magnetic field configuration. Each 1° of the decrease of the cusp latitude can be caused either by 14 nT decrease in *Dst* or 0.7 increase in *Kp*. Changes in the solar wind dynamic pressure P_{sw} leads to smaller effects. The IMF vertical component practically does not affect the magnetic field configuration, providing the other parameters (*Dst*, *Kp*, and P_{sw}) keep invariable.

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